# A FIELDTRIP TO NATURAL BRIDGES

**By Todd Newberry and his students**
(revised 2001)

## INTRODUCTION

"Am I ready for this?"

As budding and seasoned naturalists, we ask ourselves this question all the time. Fieldwork puts us face to face with nature's full variety and complexity. There's so much to try to take in, to notice at all, that all we can do is memorize names and hope for rain, right?

Well, not exactly. For one thing, nature goes right ahead in the rain. For another, while species names do matter, just as your own name matters, good fieldwork involves more than merely naming the beasts. Once you have met them (names), you need to try to make sense of their lives. After all, that is what "getting acquainted" means, whether with other people or with other species. Getting acquainted involves ***asking good questions***. In zoology, this means ***asking questions about function and design that the animals themselves can answer, and detecting the animals' own answers, not just yours***.

Natural Bridges is not a controlled habitat, not like the Monterey Bay Aquarium. And it endures a lot of natural and human disturbance. Right away when you arrive on the intertidal shelf where we will focus our efforts, look for signs of this impact – where the algae are (and aren't), where and how the rock is worn (by surf, by feet), the shapes and sizes of tidepools and the condition of their edges. And stop a moment to realize this: You are walking on the tide-exposed bottom of the sea – yes, the bottom of the sea! This intertidal bottom extends from the backbeach base of the cliff to the drop-off at the seaward edge of the shelf.

To help make sense of intertidal shores, ecologists recognize three more or less distinct zones: low, mid, and high. Why these zones should be distinct, like broad bands, and not blend more gradually into each other is a surprisingly intricate matter we won't get into now, but BETWEEN PACIFIC TIDES (5th ed.) does. This is a fieldtrip, not a book group, but we can recommend BPT as good at-home reading. BPT is organized by how protected the place is (Natural

Bridges is protected outer coast), what the substrate is (rocky, sandy, muddy, woody), and which intertidal zone is at issue. Then it introduces some of the organisms and some of what we know about their lives – just what you are finding out on your own.

Look at the whole shelf again. Get an idea of where the low (usually underwater), mid (often exposed for hours at a time), and high (dry for days or even weeks at a time) tidal zones seem to lie. Trust your first impression; don't worry if you're wrong. (Dare to be naïve!) The point is to get started in nature. What clues seem to help you discern these zones? What things confuse you about them? We are visiting this shelf at low tide; in your mind's eye, try to picture its then-submerged features at high tide. Pause now, get out some index cards and a pencil, and try to TAKE YOUR FIRST FIELD NOTES – whew! With so much to record, why isn't taking notes a snap?

Physical factors determine where organisms can exist, but interactions between organisms determine where they do exist. (Better reread that statement.) Have you noticed that the entire intertidal region below the very highest reach of the sea seems to be "marine," even though the highest intertidal surfaces are dry land 98% of the time? The merest touch of the sea seems to overwhelm the land. How odd. Why shouldn't the terrestrial biota gradually peter out descending the intertidal levels, the way the marine biota gradually peters out ascending them? From this desert-like uppermost stretch of sea-bottom to where the intertidal shelf drops into the waves, what ecological forces and factors besides just the tide's rise and fall (just?!) might cause zonation or might obscure it? Why might exposure to air – such as right now, while you are here – be so tough on some marine creatures but not on others? Are there intertidal places (other than tidepools) and organismal designs that somehow (how?) stay wet even when the tide is out?

Every organism lives in a web of circumstances. Predators hurt and kill, resources provide energy and materials and other wherewithal, competitors vie for limited supplies, symbionts give and take. Cues from the habitat regulate the life cycle's progression, sexual mates tie mortal generations into ongoing populations, "malentities" (disturbances, just bad luck) intrude. A life cycle, zygote to death, must cope with its manifold environmental predicament, with its web of circumstances. From this complex relationship emerges the arithmetic of natural selection. Stop again for a moment and consider that "natural selection" is more than a slogan. It really is going on; its agents are scrutinizing every life around you – and yours. We are inescapably players in "the ecological theater and the evolutionary play."

## SOME GEOLOGY

Check out the rocks you're standing on. The layers of rock here formed during the Miocene Period, 7 to 10 milli on years ago. It takes a wild imagination to conjecture what California's Miocene shore looked like at this latitude, or even where on the map ("where on earth") this particular stretch of shoreline was back then – probably far south of here. This shelf is being raised from the sea during quakes. But it is being worn down, too: by the sea, by rain, by clams and sea urchins that bore into it, and now even by people's feet.

The substrate here is soft mudstone that was deposited as fine oceanic silt, covered in turn, and pressed into rock deep underground. Then it was re-exposed as the sea washed away the younger, overlying strata that still form the cliff behind the shelf. At the other end of Monterey Bay are stretches of hard Cretaceous igneous rock and a very different intertidal world of nooks and crannies with a rather different suite of shore organisms.

A crack that (word has it) is a spur of the San Gregorio earthquake fault runs right through our shelf. The crack, tight and seemingly shallow in the upper tide zone, hosts a few curious very-high-tide pools. Take the time to follow the crack and its inhabitants along its length down into the low tide zone, where the sea has deepened the surface scar into a prominent crevasse. The main part of this active fault lies offshore. To our east, the San Andreas fault quaked sharply in 1989; the San Gregorio fault could, too. From this shelf, you can trace the spur inland as it scoots under that clifftop mobile home and heads (uh-oh) for town.

The many tidepools are another striking geological feature of this shelf. Not all intertidal shelves have such fine pools. Some of our tidepools appear to have formed the way potholes do in torrent streams; heavy surf-spun boulders have gouged the depressions in which they are confined, in mortar-and-pestle fashion. Find a few of these curious pools. Now try to find tidepools that probably formed in another way (formed how?). Now compare the inhabitants of apparently two sorts of pools in the same tidal zone. From your observations, can you make any interpretations? Can you distinguish which is which – that is, which are your observations and which are your interpretations? Making this distinction is a critical investigative skill.

## NOW WHAT?

Now you have a beginning acquaintance with the Natural Bridges intertidal shelf as a physical place to live. What's next? What's next is hunkering down, sometimes quite literally prostrate, with a few of the shelf's inhabitants, and sustaining your focus. Focus: keep your observational and interpretive focus. When it wanders, as it is bound to, like an untrained puppy, call it back.

To help you, we have worked up brief comments and questions about nine prominent species or groups of intertidal animals. Select only two or three animals/questions to focus on. For today, let the others in this inventory and all the hundreds of other kinds of algae and animals here serve as the setting for just your chosen few. Leave them to others today or for another day altogether. Otherwise, you will condemn yourself to a lot of "glance and go, glance and go," a disheartening syndrome that afflicts many tourist museum-goers, usually with glum consequences. Team up to help make your work more efficient, more interesting, and more fun.

Work hard at taking notes, both verbal and (try!) pictorial. This is bound to feel forced at first. Let yourself get used to it. Your goal is a new habit: taking accurate, ample notes, like any good investigative reporter. You cannot learn this new habit in a day, but you can start to learn it in an hour.

About our questions: What you are trying to observe has to occur during your brief visit to the habitat – sure! but in fact this poses a severe practical limitation on the questions you can ask. Good fieldtrip questions invite answers by observations. Good first questions invite simple observations. When you are bent to the task, try to stick to just making observations; put off most interpretive efforts until you take a break. Postpone speculations about nature's why's – about evolved adaptations – until supper. Out here in nature, don't fret about "significance": these are exercises, not gospels. Best of all, make your questions modest. Some questions really are stupid, but NO QUESTION IS TOO MODEST. Hint: Too-big questions may conflate modest ones that can be teased apart and posed one by one.

So what questions can you pose during a fieldtrip, with any hope of getting satisfying answers?

- You can figure out the names of a lot of creatures, of course, although lots of species-identifications need books and labwork, and spending a fieldtrip nose-in-book seems to us a meager experience. But after persevering a few hours you will be able to identify swiftly at least the phyla and classes of most of the organisms you encounter.
- And you can measure the tide-out (though not the tide-in) physical conditions of the place. That is, you can characterize "the climate near the ground," which is the intimate weather these creatures actually live in. It is full of surprises.
- Biologically, some organismal structures present themselves during fieldtrips, and so do organisms' numbers and patterns of distribution, and so does short-term animal behavior. These phenomena are where your work lies.

But there it is: not very much else – not much development in a couple of hours, not any evolution except for what you might infer from some adaptive consequences and symptoms. You must satisfy yourself with investigating matters of "what?" and sometimes "how?" But we think you will find it is far better to remember your fieldtrips by the satisfaction of sure answers to modest questions than by the frustration of pretend-answers to questions about what it all means.

## AN IMPORTANT RITUAL

We have learned from the naturalist, artist, and storyteller Ane Carla Rovetta how important it is to make a small offering of ourselves to whatever we harm as we study nature. The offering she suggests is just a hair from one's head. At first, this seemed a quirky and affected gesture, but over time it has become a natural way of saying thank you. And so we recommend it now and then in this guide. Trivial in itself, this gesture nonetheless simply and quietly honors the creatures around you. And it makes one stop and think when one insults nature by hurting or killing other living things.

# PHRAGMATOPOMA CALIFORNICA

Some years, enormous aggregations of this annelid worm form hard, pillowy, brown lobes on the surf-swept walls of many intertidal platforms. The surface of a lobe is a honeycomb of openings to the sand tubes that the worms have built upon one another. At high tide the surface is festooned with the worms' little filter-feeding tentacles. Now at low tide, if you peer into a tube-opening you may see an operculum, part of the resident worm's black body, plugging the tube. The worm whose operculum you have found is an inch or two long. If you disturb them, the worms retreat far down into their long tubes.

During the summer females shed quantities of lavender eggs, males shed white sperm, and the resultant larvae of the next generation go to sea as planktonic swimmers for weeks before returning to shore (how on earth do they manage that?). The larvae find these lobes by chemoreception (again how? these are microscopic larvae swimming in surf), gregariously settle down with the grown-ups, and metamorphose into benthic worms. The growing worm uses mucus as a cement to build a tube for itself from the sand that is churning by, and then to keep its tube in good repair.

- Look at a lobe's surface from different angles – from the land toward the sea, then the opposite way. The flared tube-openings all share the same orientation. Try to describe this pattern in your notes – or, better, when words fail, as they so often do, draw it.
- Is the sand in the tubes apparently (at least by hand-lens appearance) different from the sand on the adjacent beach – does it have more consistent grain-size, a different mineral composition?
- Are all the tube-openings in a lobe the same size? Or is there a describable size distribution to them over the surface of the lobe?
- Do the sites of lobes or their shapes have any apparent relationship to exposure to surf, or to the backflow of waves from the shelf above?
- How many worms live in, say, $100cm^2$ of lobe? How much lobe surface is there at Natural Bridges? How many worms live at Natural Bridges?
- With a knife-tip, excavate a single worm tube from among the others at the edge of a lobe. Now carefully scrape and slit the tube open lengthwise to reveal its denizen. Give the worm a hair from your head to make amends for this fatal insult you have just committed. (Why? See p.4 of this guide.) Now, with a hand lens, compare the worm with the drawings in this guide, so you find its tentacles, its operculum, its gills, some of its complex mouth, and its narrow posterior portion. When undisturbed, the worm keeps this rearmost body region folded up against its body to help start fecal pellets on their way out of its tube – very clever! When you are done, feed the worm to a sea anemone and closely observe that animal's behavior. For sure, be it this worm or any creature whose life you have disrupted or even sacrificed to make it "food for thought," don't just toss it away thoughtlessly.

# POLLICIPES POLYMERUS

Gooseneck barnacles are crustaceans, as are crabs, shrimps, even the pillbugs of gardens. And of course crustaceans, along with spiders and insects and a few others, are arthropods – invertebrates with legs. Their exoskeletoned bodies are hard-skinned fuselages, as opposed to internally boned and soft-skinned vertebrate bodies. Crustaceans and other arthropods periodically molt their skins – their fuselages – and secrete new ones as they grow larger. (Why, then, don't mollusks molt?) Maybe this is a crimp in their style. Or maybe, on the contrary, it is a neat developmental trick that arthropods have hit upon: prefabricate new parts to deal with the new challenges of larger size and then – voilà – don these new features fully formed during a molt, like Clark Kent going into that phone booth and emerging as Superman. For a barnacle the trick is more complex. It molts the skin around its moving parts, but the outermost husk we tend to call "the barnacle" grows by the enlargement of its constituent plates, the way a turtle's shell does. In goosenecks these many separate plates in its bivalved shell (actually its carapace) are easy to see. In "regular" barnacles the plates of their volcano-like husks are much more obscure.

Several kinds of familiar "acorn" barnacles live scattered widely on the rocks, but goosenecks prefer sites where the surf hits hardest. Goosenecks' planktonic larvae – their life cycle's swimming stage – settle on adults, then creep down the adult stalks to join the crowd, and so clusters develop. Acorn barnacles feed by rhythmically sweeping the water around them with their frilly legs to filter out tiny prey. Look for them doing this in tide pools. Goosenecks spread and hold their much leaner legs in the current of passing waves and can capture even small fish. Squeeze a gooseneck barnacle hard edge-to-edge, as though you were popping a pea pod, to force its spidery hidden body out from the carapace and in that way see its scary predatory appendages. If you do this, of course you should offer the barnacle a hair from your head (Why? See p.4 of this guide.)

- Is there any orderliness to the distribution of gooseneck barnacles of different sizes within a clump? Do the youngest, tiniest ones themselves seem to have any pattern of distribution – say, higher or lower on stalks, more on outer or inner adults in the clump?
- Most of the barnacles in a cluster "face the same way." Examine a cluster from several angles to discern this coincident orientation of its members. Do the members of a nearby cluster face that same way? What ambient factors seem to be correlated with these orientations? Speculate: what benefit might the barnacles gain from their orientation? What "critical observation" (see Tegula about them) might test your hypothesis?
- The carapace's plates are as orderly as those of a turtle's shell. Comparing smaller and larger goosenecks, do some of these plates more than others seem to enlarge with the carapace, the way some plates more than others enlarge as that turtle's shell grows?
- Where Pollicipes and Phragmatopoma meet, what do the margins of the barnacle clumps and worm lobes look like? Who "wins"? How would you test that conjecture?

# TEGULA FUNEBRALIS

Black turban snails are obviously snails, but so are cap-shaped limpets and shell-less land and sea slugs. Along with chitons (see Nuttallina in this guide), squids and octopuses, clams and oysters and mussels (see Mytilus), and several less familiar groups, snails are kinds of mollusks. Your basic snail crawls about on a broad muscular foot, lugs turtle-like a shelled and usually coiled “visceral hump” that holds most of its body, and has a well-developed head and a muscular mouth with a rasping tongue. While embryonic or larval, snails undergo a striking 180˚ permanent twisting of the body at the “waist” that puts the otherwise-posterior gills over the head, the best place in a benthic crawler for efficient respiratory water-exchange. Unfortunately, this twist also puts the anus above the head instead of nicely derrie_re. Snail lineages have modified these basic traits, especially to cope with the sanitation problem of the anus’s “post-torsion” position. Tegula pretty much retains the unadulterated traits themselves, but the conic coiling of its visceral hump (and so of its shell) departs from the planar coiling of the fossil record’s early adult snails. Try to picture in your mind how a snail must grow around an axis to make a conical spiral.

Turban snails crowd together during low tides and all day, and spread out to graze on nocturnal high tides. As with so many intertidal invertebrates, so also with these snails: they all look about the same size. The tiny high-tide snails that look like baby Tegulas are mostly periwinkles, various species of Littorina. Young Tegulas usually have the same stout shape and worn, pearly apex that adults have. But where are they? These snails do live a long time: the sturdy black turban snails at Carmel Point live 20 to 30 years, while Natural Bridges’ daintier ones may be 5 or 10 years old. Are the youngsters in a nursery somewhere else – say, subtidally just beyond the shelf? Maybe, despite their parents’ habitual reproductive “success,” as measured by quantities of zygotes, so few planktonic larvae survive their offshore weeks that scarcely any survivors ever join the shelf’s population. How would you solve this demographic puzzle without devoting years to it?

- How fast do turban snails move, for example in cm/minute? Can you vary their pace with an attractant like some food or a repellant like a dangled seastar?
- Does the Tegula population density differ per tide pool according to tidal height? or according to other characteristics of tide pools?
- You can’t answer this next one on just one fieldtrip: Do turban snails have home tide pools? But what would you do on this fieldtrip in order to answer this question swiftly on the next?
- Do the aggregated Tegulas favor darkness, the slope, coolness, or some other particular physical feature out of the several that prevail where they gather? To test your answers and explore the snails’ behavioral stimuli further, try some experimental observations using a pool cover of some sort, a mirror as a solar flashlight, splashing water, gently changing the temperature (how?), putting chemicals from algae or a seastar or even from you into the tide pool, etc. To the extent a few (and which?) observations allow or encourage an interpretation, what does Tegula seem to know about its world, at least as revealed by what it does?

- But now, a big challenge: *what observation might rule out your interpretation* (that "it knows X")? This is the most powerful kind of observation; it is called a critical observation, because it poses a crisis in the life of an interpretation (or hypothesis). Truly critical observations are often ingenious, always rewarding. Interpretations that do not lend themselves to critical observations at all are weak ones; those that survive critical observations gain strength thereby. This is hypothesis-testing, the very heart of science. At every step, observations are in charge, even if interpretations (hypotheses, theories) get the headlines.

Turban snails have various consorts. One is the tall-spired little black limpet Lottia asmi. (This is the Collisella asmi of BPT and most other references, and before that it was Acmaea asmi, which shows that taxonomy is alive and well.) It lives on the shells of a small percentage of Tegula here. Once you find a few L. asmi you will see them everywhere, but almost exclusively on turban snails. They are strikingly different from the many low-spired limpets and the slipper snails (Crepidula) that also ride these snails.

- What percentage of a pool's Tegula population carries L. asmi? Does this differ from pool to pool, from one tidal level to another? Can you now calculate the whole shelf's population of Tegula? and of L. asmi?
- Does the limpet ride only on a certain part of the turban snail's shell?
- How does the black limpet – or for that matter how does any limpet at all – get onto its host snail? (Yes, with patience and a cooperative limpet you can watch it do this.)

Finally, three species of little hermit crabs of the genus Pagurus quickly take over empty Tegula shells.

- Where are these crab-occupied shells vis-à-vis the living snails?
- Look at their big claws; left and right, they are built differently. Does the crab use them differently even while you watch?
- If you get (gently, ingeniously) a hermit crab out of its Tegula shell, and present it with a fresh shell, how does it examine and acquire the shell as its new home? What if the new shell already has a crab occupant of apparently the same species? or of an apparently different species?
- Do Pagurus-occupied Tegula shells also have symbiotic Lottia asmi limpets on them, just as shells of living snails do?
- Do these little hermit crabs occupy the shells of other snail species? Of course they do. But do they have a preference? That's a harder, statistical nut to crack. And might hermit crabs of subtly different species have subtly difference host preferences? You can't answer that question today, but how would you go about answering it if you had a week?

## CHITONS

The West Coast is chiton heaven. By one estimate, 100 of the world's 500 species of this molluscan class live here, 50 of them around Monterey Bay. Mostly they graze on diatoms and small algae. The eight overlapping plates that make up a chiton's shell fit together like a spine that is adjusted by the muscles of a fleshy marginal girdle. As a result, these flat animals can bend to fit into crannies, and if taken from the substrate they usually roll up. Basically, a chiton's anatomy consists of just a tough foot with the soft parts of the body (in a flattened visceral hump) compressed into the sole. Pink and white chitons lurk beneath rocks, huge reddish boots crawl in the large pools at Pigeon Pt., and chitons of all sorts with exquisitely sculpted and striped shells and girdles cling to low-tide rocks all along the coast. This is an elegant bunch, whose surface designs and decorations rival fine weavings.

On the granite rocks around Monterey, massive <u>Katharina tunicata</u> thrives at low tide where the surf is strongest. Its scarred whitish shell plates are almost covered by a heavy, black girdle of leathery flesh. Here at Natural Bridges, hairy-girdled <u>Mopalia muscosa</u> grips surf-swept rocks at low tide. The smaller, mid-tidal <u>Nuttallina californica</u> shares this high-energy habitat. It has fairly prominent shell plates, splotchy browns and olives and whites in its spiny girdle, and an orange underside to its girdle. But still it is a cryptic animal; you have to train your eyes to see it. It grazes food with a rasping tongue armed with iron-laced teeth that are magnetic enough to influence a compass! (Combing the beach's sand with a magnet, you will retrieve chiton tongues.)

The particular biology of most chitons is simply unknown. Perhaps these animals are too modest to attract the attention of many naturalists. It is a taxon just waiting out there to make another zoologist's career.

- <u>Nuttallina</u> rests on a home scar, which it somehow finds again after moving about to feed. Devise some experiments that would isolate and identify the chiton's means of homing navigation. Short of that, how might you simply trace the path of the chiton's excursion?
- Carefully work a spatula or butter knife under a chiton's foot and gently pry it off the rock – no mean trick. With what force it manages to cling! – using what: suction? glue? By now the chiton probably has rolled up. Submerge it on your hand in a tide pool and let the animal uncurl and crawl onto your finger. Can you feel the muscularity of its foot? Turn it over underwater: can you find the many gills alongside its foot? Can you find its little mouth? Can you find its anus? How do you know which is which?
- Describe in your notes the plates' and girdle's more easily seen structures, and draw the animal's pigmented and sculptural designs. Later, maybe this evening, speculate about what these features might add to a chiton's quality of life. What have they added to yours?

## LIMPETS

Limpets are non-coiled, hat-like snails. Some 20 limpet species live here, quite aside from the related "volcano" limpets <u>Diodora</u> and <u>Fissurella</u> and the slipper snail <u>Crepidula</u>, a distant cousin. Today, give the kinds of limpets you find your own vernacular names or codes (L-1, L-2, ...) and record the traits that identify each such "species" for you. The challenge is first to find limpets at all, then to distinguish some consistently from others (look for a half-dozen kinds), and finally to make rudimentary sense of their ecological distribution on and around the shelf.

Traits that will help you identify kinds of limpets include side-of-the-foot color, inner-rim-of-the-shell color, skew (or its lack) of the cap apex toward the snail's head, straightness or curvature of the shell's anterior slope, shell sculpture like ridges and bumps, striped or spotted shell patterns or their absence, and the shape (narrow, rounded) of the shell's outline.

If you have looked at Tegula funebralis you already may have seen its consort limpet Lottia (=Collisella) asmi. And if you have explored near the outer edge of the shelf you may have found "limpet farms" and their big but secretive farmers Lottia gigantea. Lots of tiny limpets ride on turban snails and gooseneck barnacles and other bigger animals and even on some seaweeds, and when your eye gets accustomed to them you will find limpets singly and in clusters on rocks from the lowest levels well into the mid-tide zone. Of course, when we visit the shelf almost all exposed limpets are having siestas. Limpets in tide pools may be active, or they, too, may be quiescent during the day.

- Do some kinds of limpets but not others rest in one-species clusters? Does a certain mix of species clump together?
- Do some resting limpets favor more secluded places than others?
- Do some kinds of resting limpets seem to adopt predictable surfaces and positions vis-à-vis gravity or substrate irregularities or the likely eventual flow of water around them or other environmental forces (sunlight, wind)?
- Is there evidence (e.g., paths, scars on rock) that one species or another "homes" repeatedly to the same resting spot?
- Can you connect limpets' ecological habits with morphological traits like shell sculpture, shell height, size, pigment pattern?
- Lottia gigantea: Examine one or two of this limpet's vigorously defended territories, once someone has pointed out a few to you. What other creatures persist on these farms? any other L. gigantea? The farms' have a distinctive hue, sometimes more easily perceived from afar. See those regular arcs of little scrapes? Each scrape is left by the limpet's rasping tongue as it browses its farm's crop of diatoms. Try to follow a limpet's course through its whole latest bout of feeding, by following the connected arcs of its tongue-scrapes. Then drape yourself over the farm to look for the farmer, which most probably is off to one side or even over the edge on an adjacent vertical surface. Speculate: Is the limpet hiding? If so, from what? Or is this limpet safe in plain sight? How would you test your interpretations with critical observations? (See Tegula about critical observations.)

## MYTILUS CALIFORNIANUS

The mussels that form beds on our shelf go by the vernacular name of "California sea mussel" – how provincial! Other species ("bay mussels") inhabit our bays and estuaries. Mussels attach themselves to hard substrates with protein "byssus" threads. Pull on an animal to test its threads' surprising strength. The animal tends to stay put, but it can move very slowly by breaking some threads, extruding new ones from a byssus gland next to its little foot, and then using its foot to place and glue the new threads.

Mussels shed great quantities of gametes. The planktonic larvae grow for weeks at sea, then return to shore to settle and metamorphose into benthic young. Of course, so much that is mysterious lurks in that textbook sentence! For example, how do the larvae find their way and make their way to shore, in such a big ocean? They grow fast, to 3” in a year, then can live a long time and get twice that size if the habitat is mussel-friendly.

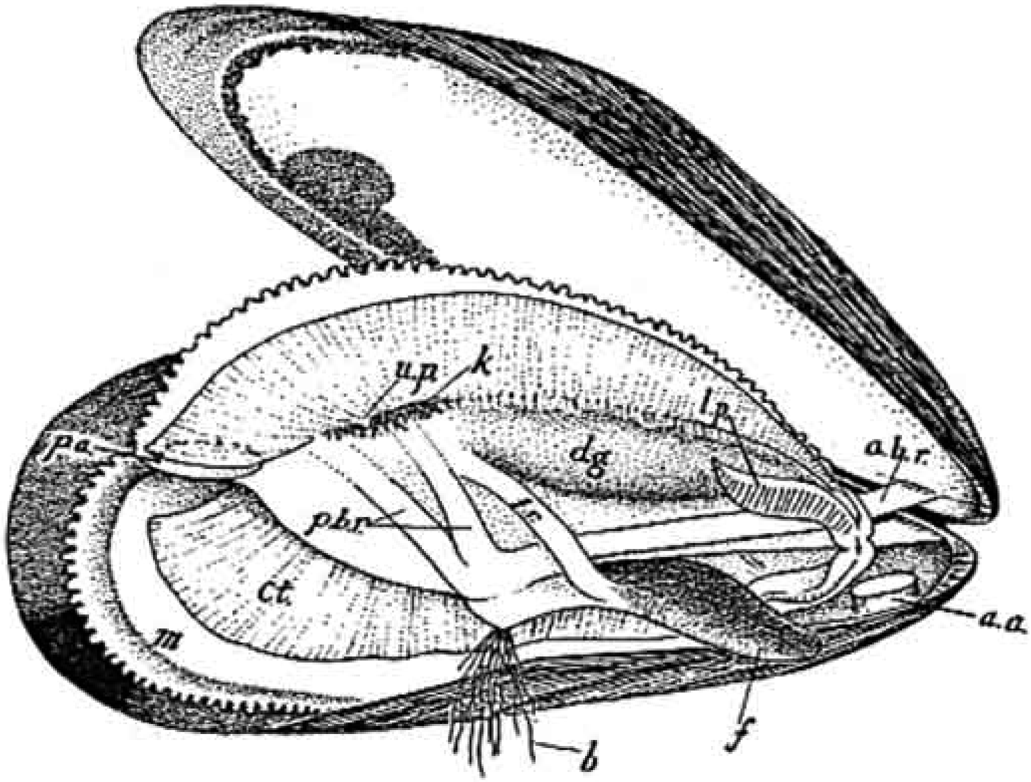
Everybody picks on mussels. Predaceous snails bore through their shells and lap their innards. Ochre seastars insinuate their stomachs between the mussels’ shell valves and digest their soft tissues. Shorebirds and gulls yank little ones free and shatter them. Crabs crush them; people do, too, or even shovel them up wholesale. Winter storms sweep quantities of them from the shore. All this afflicts the settled mussels; God only knows what slaughter the larvae endure at sea. What a demanding web of circumstances this life cycle has!

Mussels are filter-feeders; they use elaborate tracts of cilia to drive water through their huge gills and extract fine food particles from the current. But this set-up is altogether hidden, out of sight inside the shell. It is time to open a mussel. Yes, this kills the animal. Contribute a hair from your head to make amends. (Why? See p.4 of this guide.) And then, when it has served you as food for thought, don’t just toss the mussel away; feed its soft tissues to an anemone or to another focus animal and observe closely.

- With a knife, open a mussel by slicing through the big adductor muscle near the broad end of the bivalved shell. Once inside, even in this rough dissection you can find the delicate flap-like gills on each side of the body, tiny palps beside the mouth at the narrow end of the body, the pendulous little foot and its byssus gland, the gonads (in females reddish ovaries, in males white testes), and the tough white adductor (shell-closing) muscles at either end of the body. Kendal Morris’ superb drawing will help you.
- The tissues at the very edge of a living bivalve’s shell are marvelously complex. Look at the frilly flesh along the non-hinged margin of the shell. There are three lengthwise folds. They perform different tasks: the outermost one secretes the black organic surface of the shell, the middle one provides sensory functions (in scallops it even makes a row of eyes), and the inner fold presses against or actually seals with the fold opposite to close the gap between the shell valves with a continuous tissue. A band of the skin just back from the margin secretes a “prismatic” layer of shell, and the rest of the skin washes the internal surface of the shell with mother of pearl. The splendid gills, the bright gonads, the little foot with its byssus gland, a skin that makes mother of pearl, and now these marginal folds – how often have you eaten mussels and never noticed?

Now, by imagination and dissection, you have some idea of mussels as organisms (that is, as life cycles) and as bodies. Here are fieldtrip questions about the animals to deepen your acquaintance:

- Where are the settled young, if they are around at all? Run a size-vs-quantity census of a 1x1-foot patch high in the mussel bed and of another one low in the bed and see if these shed any light on the mystery. Look right down to the rock for tiny mussels – look under the grown-ups, amidst the byssus….
- Since all these other predators love to eat mussels, you might try one, too. But don't try in the summertime, a risky season to eat any open-coast filter-feeding shellfish: they concentrate the plankton they eat, and sometimes summer plankton includes toxic forms. Numb lips and tingling fingertips? – uh-oh, off you go to the doctor.
- Probably to facilitate their filter-feeding in the surf's strong currents, Pollicipes barnacles and Phragmatopoma worms orient themselves in relation to the surf and backwash. Do mussels? (If not, speculate why not.)
- The mussel's adductor muscles pull the valves of its shell together. But what spring opens the valves? Again use that handy mussel that you just dissected. After you feed its soft parts to an anemone, examine the hinge line of its shell for a long brown ligament that the contracting adductors must distort in order to close the valves. There it is, running along the margin. But, by contracting, do the adductors stretch the ligament's exterior edge or do they compress its internal edge? Nothing is simple.
- A mussel's shell is strong all out of proportion to its thickness. Partly it is of ingenious geometric design, like a dome. But also – a materials scientist's dream – it juxtaposes several thin layers like plywood. After you have figured out how the valves open and close, break one and examine its cross-section to see if you can answer *for yourself* the question, "What makes the shell so strong?" A hand lens is essential for this, as it is for so much else in life.
- The mussels higher up in the bed have stouter shells than those lower down. Precisely what part of their shell valves makes them stouter? The comparison of complex shapes, at first so unwieldy, proceeds more easily if you take the shapes apart in order to compare the dimensions of their components one by one.




## GENERAL ANATOMY OF MYTILUS.

aa = anterior adductor muscle (cut to open shell)
abr = anterior byssus retractor muscles
b = byssus threads
ct = left ctenidium (=gill) (right gill is folded back)
dg = digestive gland
f = foot
fr = foot retractor muscle
k = kidney
lp = labial palps (beside mouth)
pa = posterior adductor muscle (cut to open shell) (partially obscured in this drawing, but prominent in the opened animal itself
pbr = posterior byssus retractor muscles
up = urogenital papilla

The narrow mussel's anterior end is to the right, dorsal edge is at the top. The soft parts in this particular dissection lie in the animal's left valve "on the half shell." The frilled-edged tissue in the left valve is the middle, sensory fold of the skin. The right gill has been folded back to reveal structures it hides when it is in place.

The right valve has been raised like a roof. Near its posterior margin is some of that valve's "mantle line," where the skin was tightly attached. The right valve also shows the scar (stippled dark) where the posterior adductor muscle was attached.

## PISASTER OCHRACEUS

The ochre (often purple) seastar is an echinoderm: radially symmetrical, spiny-skinned with a sub-surface skeleton of intricately modified and arranged crystalline ossicles, bedecked with external gills and little "tube-feet" and tong-like "pedicellariae," and with an extremely puzzling internal anatomy. Besides seastars, echinoderms include sea urchins, sea cucumbers, brittle stars, crinoids ("sea lilies"), and a great many fossil groups.

A seastar's radial symmetry is broken externally by the pale off-center "madreporite" on its upper surface. This gritty little disk belongs to the animal's extensive and uniquely echinoderm water vascular system, which engorges its thousands of tube feet. All over Pisaster's arms are delicate gills, knobby little spines, and clumps of tiny pedicellariae. The undersurface of each arm has a long, deep "ambulacral groove" that harbors its tube feet, lots more pedicellariae, larger gills, and a big nerve. At each arm-tip a little red eye of perplexing function pokes above the spines.

At low tide Pisaster rests on shaded walls; it moves up with the tide to feed especially on the mussels that abound mid-tidally. The seastars we find in tide pools probably were stranded there by the ebbing tide a few hours ago. Pisaster attacks mussels by arching itself around the mollusk, attaching its tube feet to its prey's shell valves, stiffening its skeletal ligaments, and then contracting its tube feet to inexorably pull the valves a tiny bit apart. That effort – or even the inevitable irregularity in any mussel's closure – opens the victim just enough for Pisaster to slide in its eversible stomach. Curtains!

- Stiff as Pisaster at first seems – and often is – if one glides across the floor of a tide pool you will see that it is consummately flexible, thanks to the thousands of articulated ossicles in its skeleton, its myriad tube feet, and its ability to alter the stiffness of the collagen in its ossicle-to-ossicle ligaments. (It does not stiffen by "tensing its muscles.") Turn a seastar over in a tide pool and watch it right itself. What does its behavior suggest to you about what the animal knows about its world? How would you test your inference?
- Does Pisaster detect such chemicals as juice from an injured mussel? Or, rather – because this is all you can observe – does it *react* to these chemicals?
- Sometimes Pisaster can be caught, stomach everted, in the act of eating. Check seastars for one in this predicament. If you find one, examine its stomach quickly, before it withdraws it under such disturbance (or embarrassment).
- Pisaster's pedicellariae are almost too small to see even with a hand-lens, but if you brush an ochre seastar underwater with the back of your hand you can feel these pincers grabbing at the hairs on your hand.

## STRONGYLOCENTROTUS PURPURATUS

Between the Anthopleura anemones and these purple sea urchins, you are meeting bearers of some of natural history's longest names. Superficially these globular animals are what you would get if you folded a seastar's five arms up and together, origamilike: each ambulacral groove with its tube feet runs from the mouth up the side of the urchin to near the anus. These urchins scavenge and graze on algae, which they manipulate with their spines, tube feet, and pedicellarial pincers, and grind with their wonderfully complex jaws.

Along this coast purple sea urchins use their tough jaws and probably also their spines to bore pocket-refuges (from surf and predators) into the soft rock. The ensconced urchin snags passing debris with its pedicellariae and the tube feet scattered over its body and transfers the item to its mouth at the bottom of its refuge. Urchins dig pockets when they are little, then widen and deepen them as they grow. (Then where are the youngsters' tiny pockets?) Many seem to have dug their own prisons, slowly trapping themselves in deep cells whose old entries are too small to escape through. But that seems all right for the urchin; birds, fish, and sea otters cannot get at it, and it gathers enough flotsam to get along in a slow-paced sort of way. But disaster lurks: the many urchin pockets in the tide pools and on the edge of the shelf so weaken the substrate here that it keeps collapsing in heavy surf. The other borers of geologic importance here – "pholad" clams – tunnel even deeper into the rock. They, too, are safe from predators as they extend siphons to filter water at the rocks' surface, but their burrows make eventual geological calamity all the surer.

- If you have inverted a seastar and watched it right itself underwater, do the same with a sea urchin. With their very different bodies, they differ in the way they accomplish this maneuver. How do armless urchins use their spines, tube feet, and pedicellariae to right themselves?
- If you gently poke a sea urchin with a needle or a pencil-point, what do its spines and tube feet and pedicellariae do? If you focus a light on them (say, by deflecting the sun with a mirror), what do they do? If you brush the animal lightly a few times with a hair from your head, what do they do? If you give the urchin some mussel meat? If you touch it with an ochre seastar? In other words, in such simple ways, once again what can you find out about what the animal knows about its world, at least by interpreting your observations of what it does. Then, what ingenious further "critical observations" (see Tegula) will test your interpretation?
- Urchins have one of the most complex mouths of all animals: dozens of bones and muscles move five rodent-like incisor teeth to grind away at food. Such intricacy for such a mundane chore! Examine the mouth of a living urchin. Put an animal submerged with some seaweed in a ziploc bag. Try to see some of the oral structures at work.
- Actually get into one of the larger, deeper tide pools and census its wall for sea urchin pockets – their number and distribution, where they are occupied or empty. To report your findings, how can you make a 3D map of the walls of the pool and plot the pockets?

## THE ANTHOPLEURA ANEMONES

Three sea anemones of the genus Anthopleura thrive on the shelf. The biggest, the giant green anemone A. xanthogrammica, usually has a uniformly green oral disk (the area surrounded by the tentacles). The sunburst anemone A. sola can be as big and sometimes quite green; its oral disk has fine radiating lines. In these big anemones the often intensely green color of the oral disk is sometimes attributed to the chlorophyll of symbiotic algae. At least here at Natural Bridges it is clearly due to the anemone's own pigments, since the algal symbionts are brown. The oral disk of the little aggregating anemone A. elegantissima is about the diameter of a penny. These little anemones clone – that is, as they grow, they divide to form genetically identical progeny. As a result, a single life cycle is dispersed into many bodies. These clonemates tend to stay together along wet cracks or in very shallow mid-tide pools.

A. elegantissima is famous for the sometimes lethal fights that go on between its clones and keep them apart. Look at the margins of some clones for the no-anemone's-land around them. How might anemones in one clone recognize those from another as "not us"? These delicate animals are predaceous carnivores, and the weapons they use in these fights are the same cellular harpoons (nematocysts) that anemones and all their relatives – Hydra of high school biology, corals, jellyfish – use to subdue their prey. We barely feel their effects when we brush anemone tentacles with our fingers, but of course some other cnidarians – sea wasp jellyfish, some tropical hydroids, the Portuguese man-o'-war – are ferociously venomous even to big animals like us.

- Feed a few big anemones. What are their tentacular and oral reactions to a pebble, a piece of seaweed, an intact snail, an injured mussel?
- Here are all these big A. xanthogrammica anemones – but where are the little, presumably young ones? How about A. sola anemones – where are their young? Despite the parents' evident prosperity and their annual reproductive success (as measured by numbers of zygotes) the addition of youngsters to this shelf's stable population may well be a rare event. How might you test this speculation?
- Are the distributions of the three Anthopleura species relative to one another random (all mixed together) or skewed (different species in different sorts of places)? To answer this question, map their distributions over, say, a lower mid-tide area of 5x5 meters, incorporating surface features like grooves and tide pools.
- Can you find evidence that anemones move about? or that they don't?
- Feel Anthopleura's tentacles with your finger. They won't hurt. (But, *don't*, as students from time to time do, stick your tongue into its mouth! Or rather, if you do, don't call us for help.) Try to describe in your notes the feeling of the tentacles gripping your skin. You can even poke your *finger* down through the mouth into the anemone's sac-like gut, although this can take on a certain veterinary quality. If you do this, can you detect what the anemone has eaten lately? Whoa!